ILC Simulation for RDR

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OVERVIEW

- **Scope**:
  - ✓ Study the emittance preservation and developing further tools
  - ✓ Specification of alignment tolerances of the components
  - ✓ Static tuning and alignment studies
  - ✓ Main Linac (ML) lattice design
  - ✓ Benchmarking among various codes
  - ✓ Wakefield calculations
  - Dynamic effects and Feedback studies
  - Integrated simulations of static and dynamic effects across all sub-systems from DR exit to IP
  - Specifications for Instrumentation and diagnostics
- **Collaboration:** Within the American region, Fermilab is collaborating with SLAC and Cornell; and outside with CERN, DESY and KEK on the ML studies
- **Personnel involved:** Mike Church, Ivan Gonin, Timer Khabiboullin, Paul Lebrun, Leo Michelotti, Shekhar Mishra, Sergei Nagaitsev, Francois Ostiguy, Kirti Ranjan, Nikolay Solyak, Panagiotis Spentzouris, Alex Valishev

Main Linac Simulation

✓ Before Baseline Configuration Document (BCD)

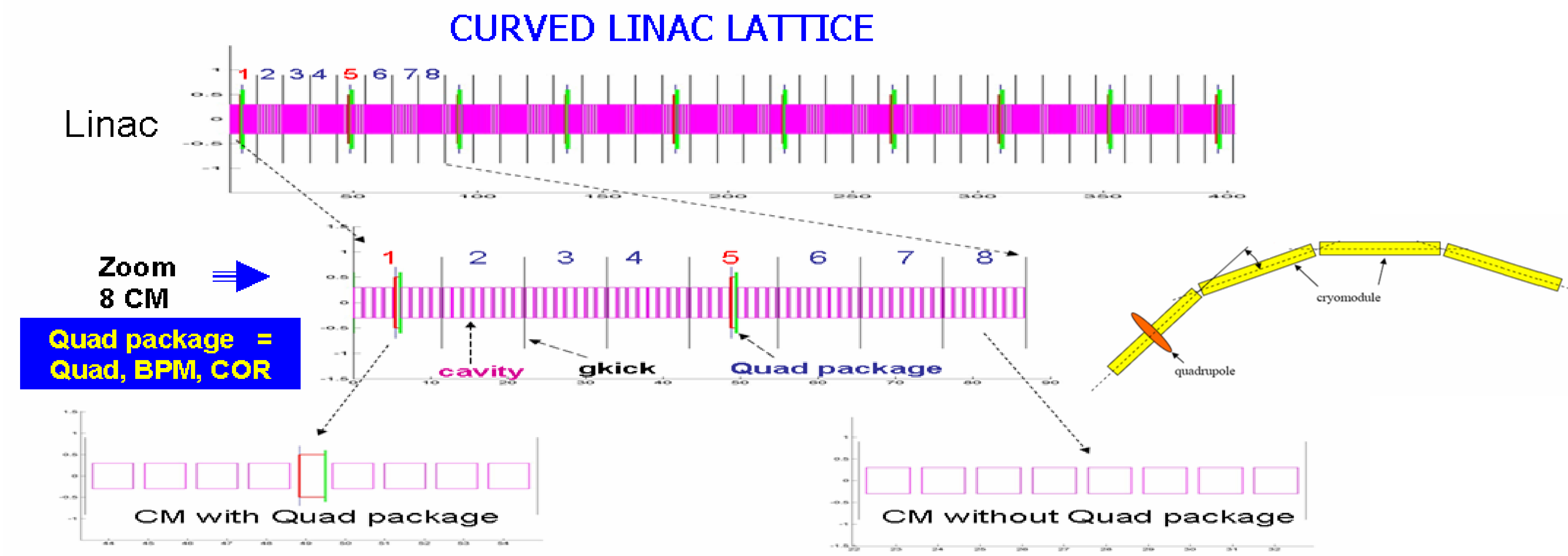
⇨ **Results presented in Snowmass,'05**

- **Study single-bunch emittance dilution in Main Linac**
- **Compare the emittance dilution performance of two different "beam-based steering" algorithms : "1:1" & "Dispersion Free Steering" under nominal conditions of static misalignments of the various beamline elements**
- **Compare the sensitivity of the steering algorithms for conditions different from the nominal**
- **Compare the different lattice configurations (with different Quad spacing)**

✓ After ILC BCD

⇨ **Preliminary results for the ILC BCD curved Linac**

Emittance Preservation



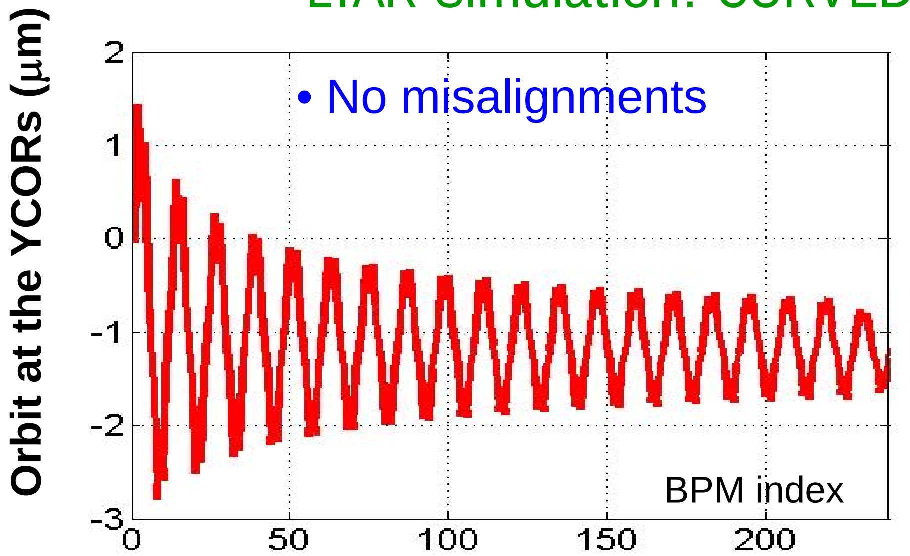
- A constant focusing lattice with a quadrupole spacing of 32 cavities and x/y phase advance of 75/60 per cell (ILC BCD - 1Q / 4CM)

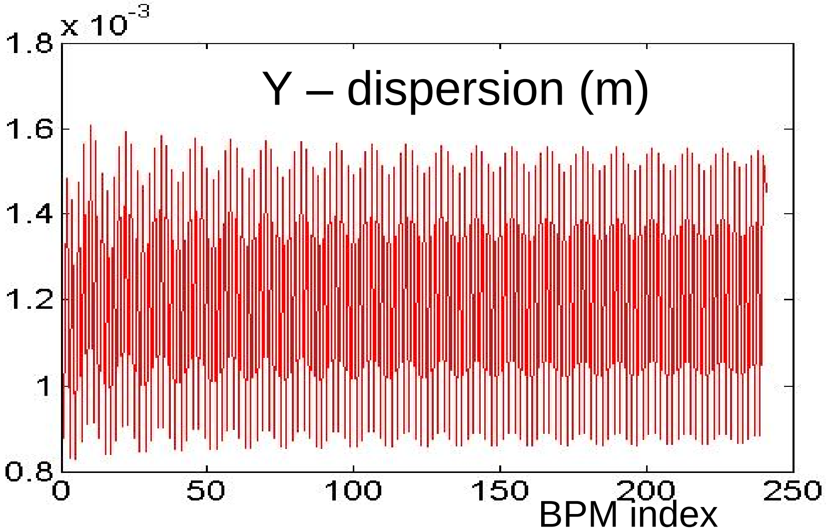
Length (m)	**:**	**10417.2m**
N_quad	**:**	**240**
N_cavity	**:**	**7680**
N_bpms	**:**	**241**
N_Xcor	**:**	**240**
N_Ycor	**:**	**241**
N_gkicks	**:**	**1920**

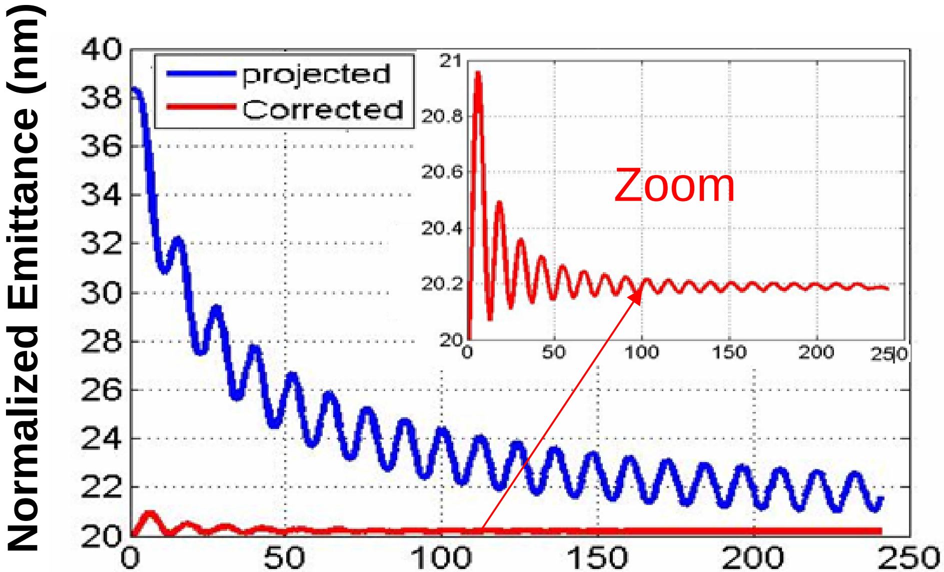
- Modifications in LIAR code to simulate the earth curvature:
  - The curvature is simulated by adding kinks between the cryo-modules
  - The matched dispersion condition at the beginning of the linac can now be artificially introduced into the initial beam

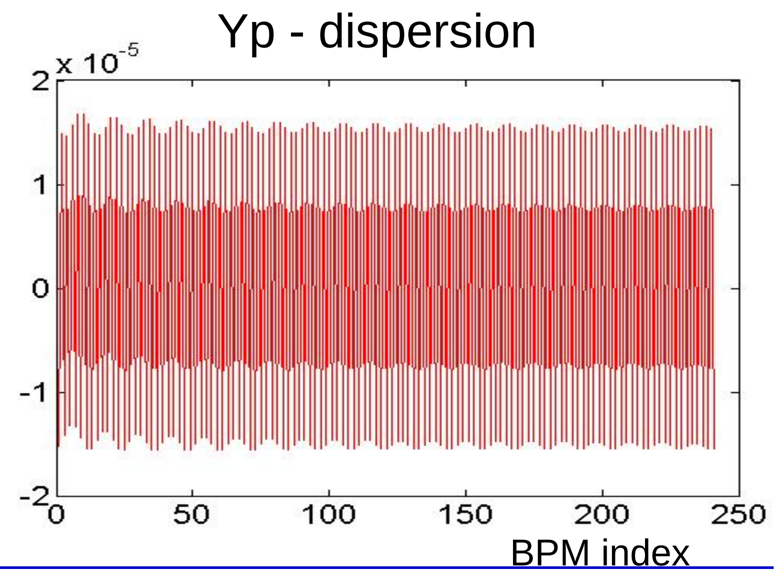
Emittance Preservation

LIAR Simulation: CURVED LINAC: ILC BCD LATTICE







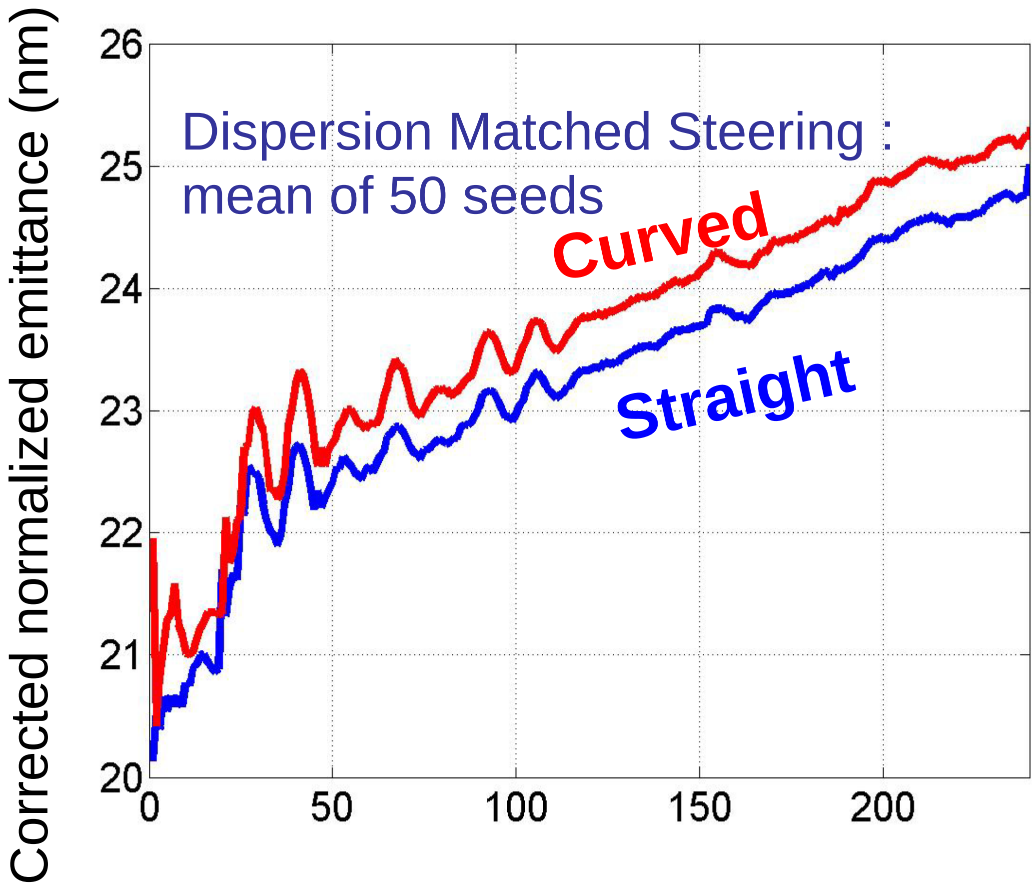


Emittance Preservation

Static Tuning: LIAR Simulation: Dispersion Matched Steering (DMS)

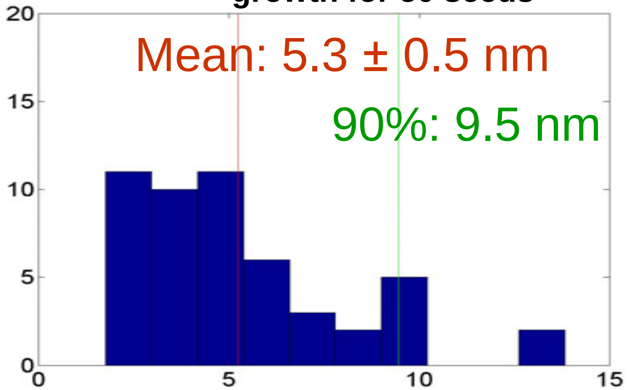
- Misalign the beamline components and perform the steering

CURVED vs. STRAIGHT LINAC

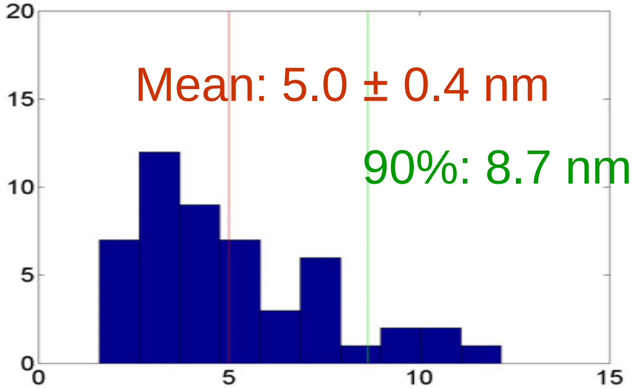


DMS parameters not optimized for Curved Linac

Distribution of emittance growth for 50 seeds



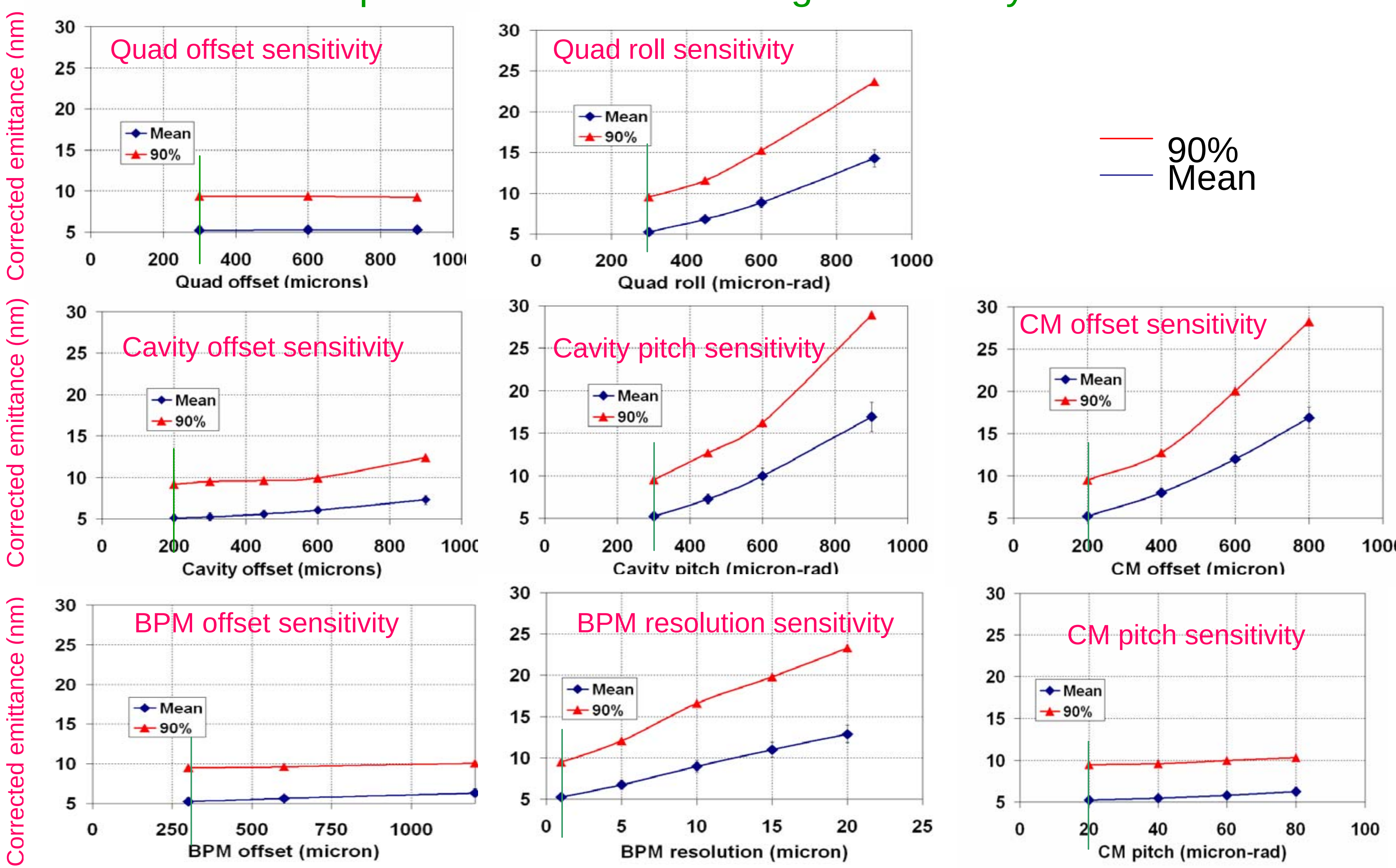
Curved



Laser Straight

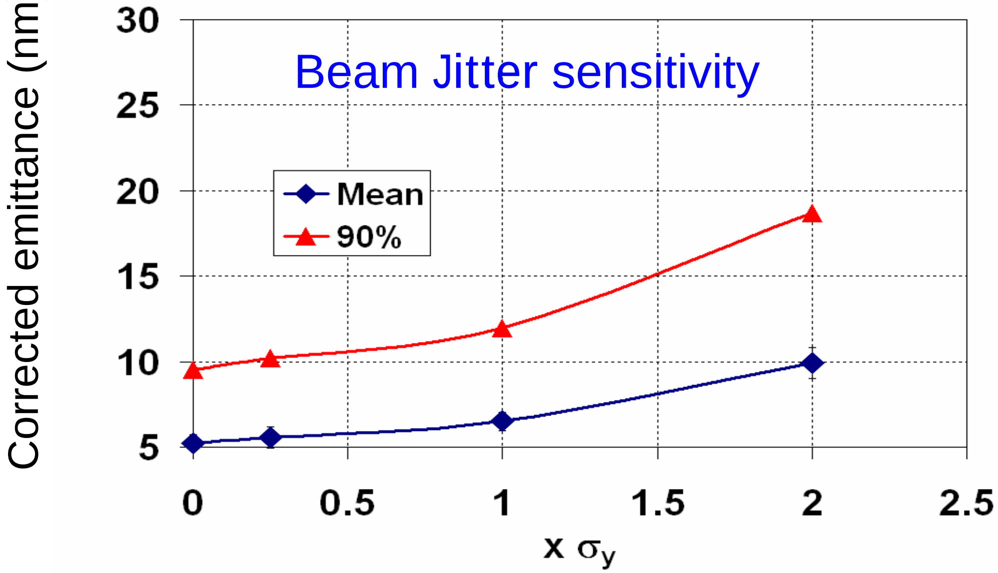
Emittance Preservation

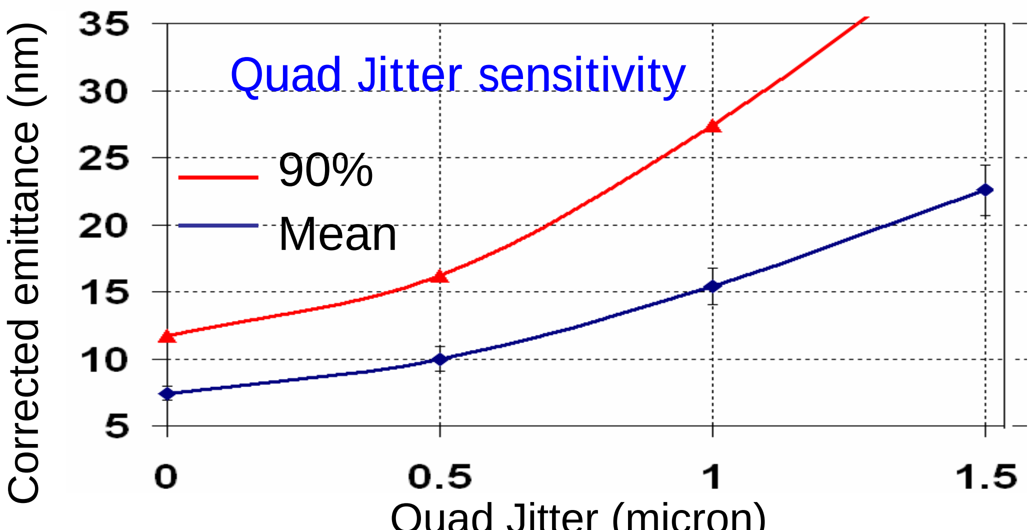
Dispersion Matched Steering: Sensitivity studies



Emittance Preservation

Beam and Quad Jitter Sensitivity of Dispersion Matched Steering





Quad Strength Jitter

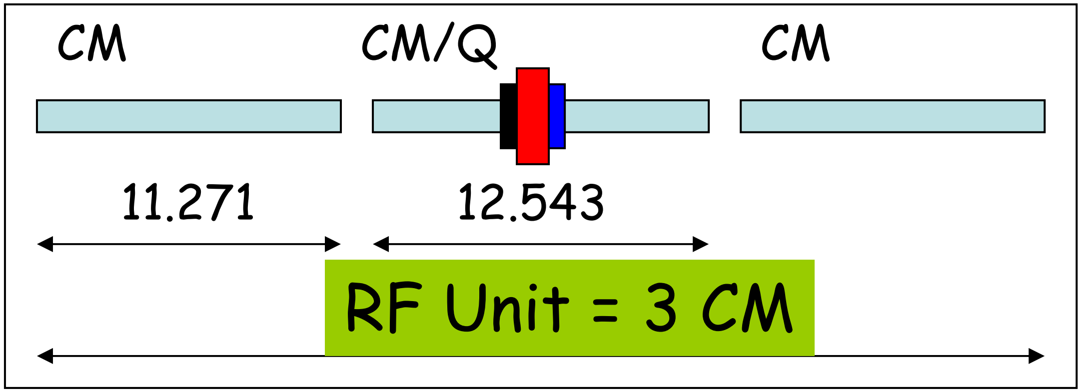
Quad strength error (dK)	Mean	90%
0.5 e-3	7.43±0.46	11.7
1e-3	7.44±0.46	11.5
2.5e-3	7.50±0.46	11.5
5e-3	7.70±0.46	11.9

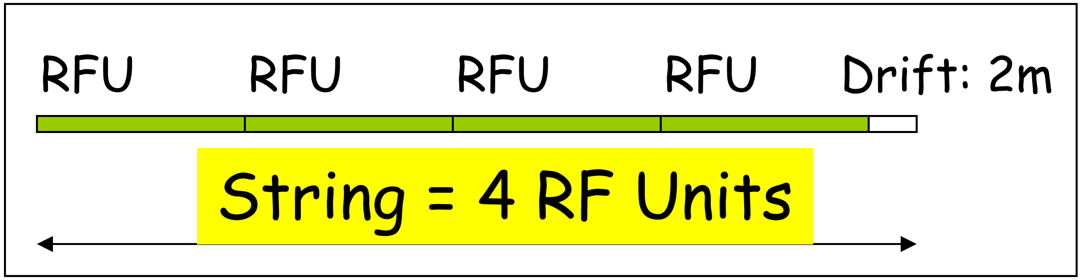
Cavity Gradient errors:

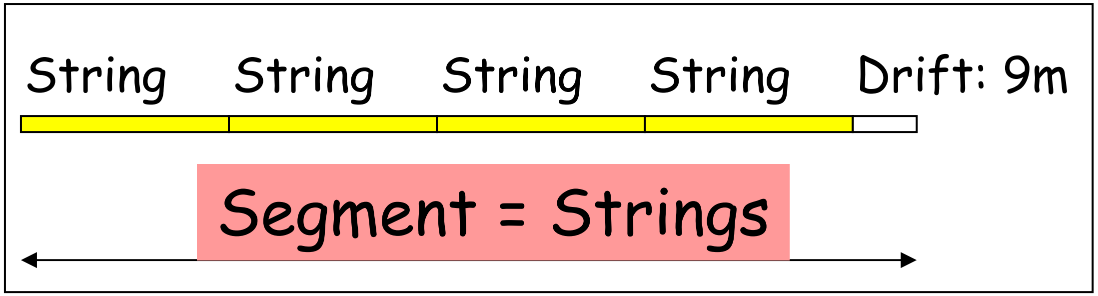
Gradient error 3% rms → emittance growth ~ 0.1 nm

ML Lattice Design

- 1 Quadrupole per 3 Cryo Modules = RF Unit (35 m)
- Cold drift of 2 m at the end of a String (142 m)
- Warm diagnostics section of 9 m at the end of a Segment (578 m)



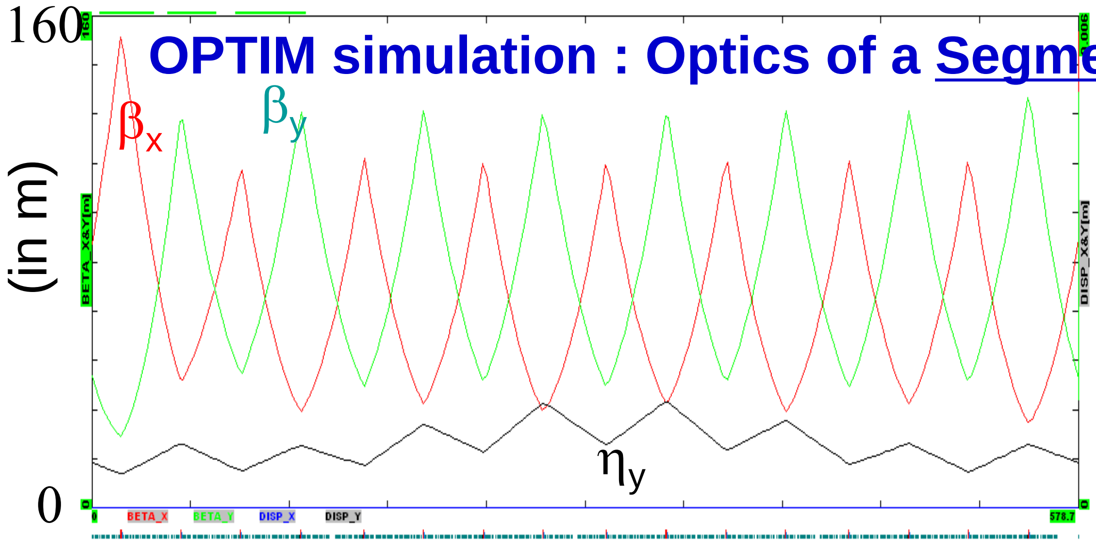




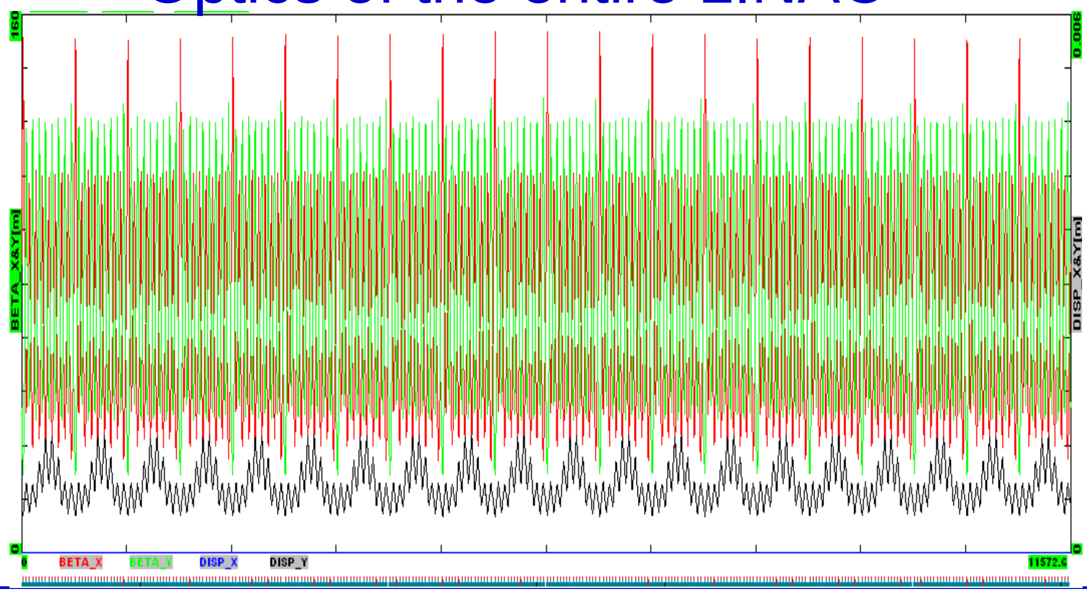
LINAC = 20 Segments

ML Lattice Design

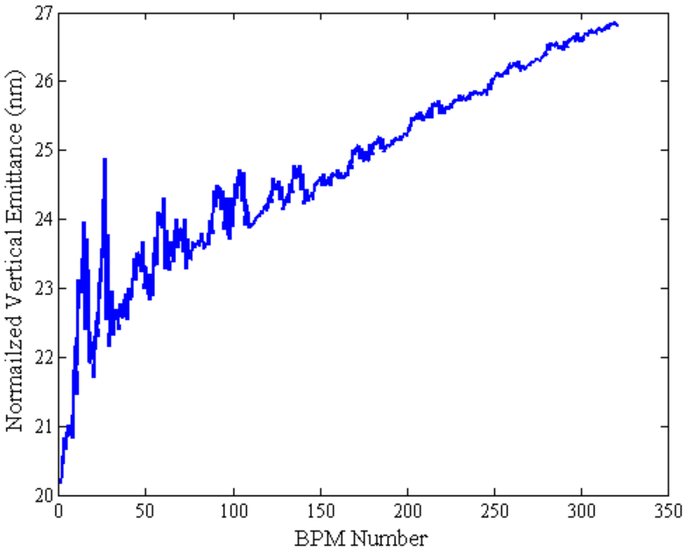
OPTIM simulation : Optics of a Segment



Optics of the entire LINAC



Mean of 100 seeds
Dispersion Matched Steering



Cross- checking

Single Bunch Emittance Dilution with static misalignments

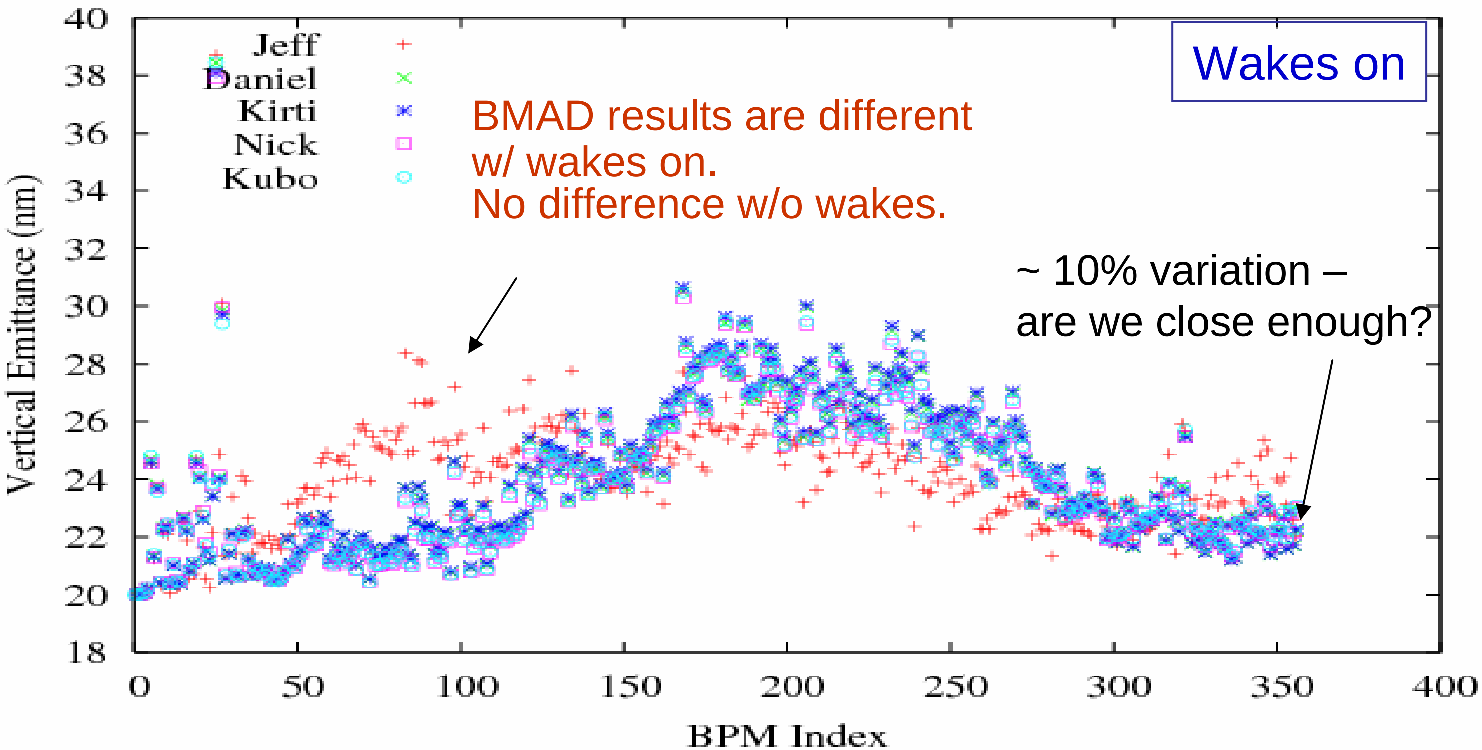
- In the various results presented during SNOWMASS and in the LET workshop at CERN, differences among the various Main Linac simulation codes were found.
- Significant differences in the emittance dilution predictions and sensitivity of the beam based alignments.
- Thus, it is generally felt by LET community to understand these subtle differences carefully and hence various analyzers have agreed to cross-check results
- Two exercises were performed

<u>Codes compared</u>

BMAD (TAO)	--	Jeff Smith (Cornell)
PLACET	--	Daniel Schulte (CERN)
MERLIN	--	Nick Walker (DESY) & Paul Lebrun (FNAL)
SLEPT	--	Kiyoshi Kubo (KEK)
MATLIAR	--	Peter Tenenbaum (SLAC) & Kirti Ranjan (FNAL)
CHEF *	--	Leo Michelotti (FNAL) –exercise #1

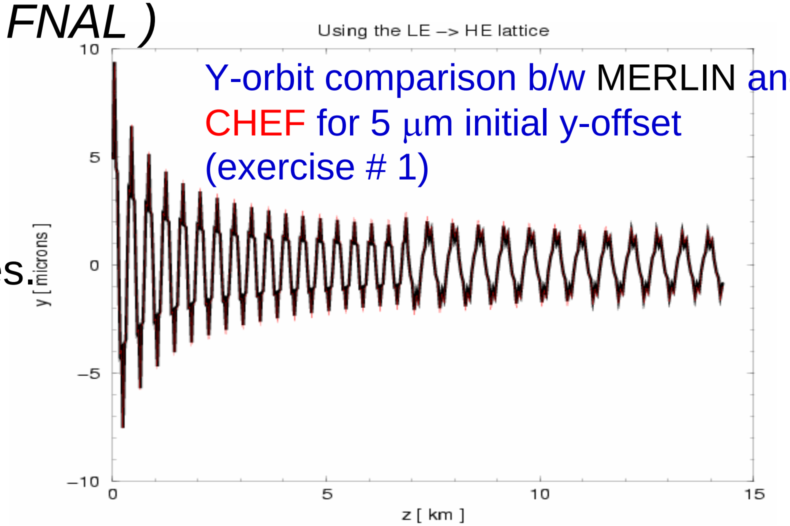
Exercise # 2 (Dispersion Free Steering)

- **Goal:** Include all misalignments and the vertical corrector's setting.
- Misalignments and vertical corrector's setting files for DFS (for Quads, BPMs and cavities) generated by using MATLIAR.
- Differences are found in reference energy calculation, integrated quad strengths, incorporation of wake effects etc. Different groups have been able to find some small bugs/differences in their code while doing these tests.



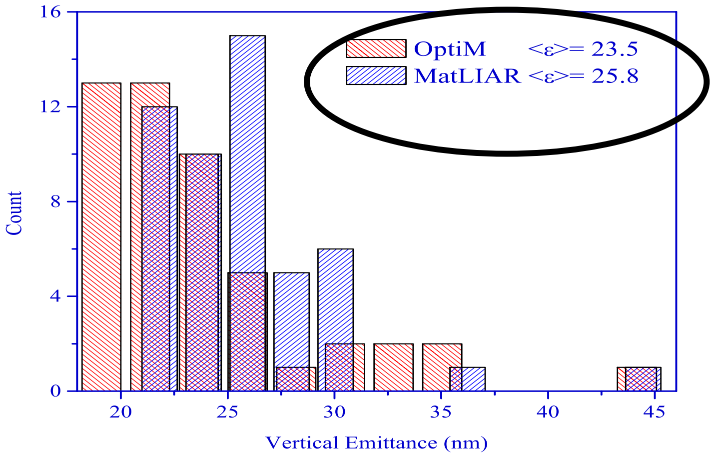
LET Simulation Tools development

- CHEF *(by Leo Michelotti & Francois Ostiguy, FNAL)*
  - Interactive program for accelerator Optics
  - Uses high level graphical user interfaces to facilitate the exploitation of lower level tools incorporated into a hierarchy of C++ class libraries.
  - GUI integrated, Linux, Windows
  - Used for circular machines and transfer lines, ***now upgrading for ILC studies***



Y-orbit comparison b/w MERLIN and CHEF for 5 μm initial y-offset (exercise # 1)

- OptiM *(by V. Lebedev, FNAL)*
  - Used for more than 10 years
  - Integrated system for Optics design, support and measurement analysis
  - Similar to MAD but with integrated GUI
  - Wake fields, tracking
  - No beam based alignment features yet



Emittance dilution in **MatLIAR** and **OptiM** with 1μm Quad misalignments in Curved ILC Linac

- Mat-LIAR *(SLAC)*
  - Used at FNAL since 2002 for LET simulations
  - New features added to support curved Linacs (FNAL)

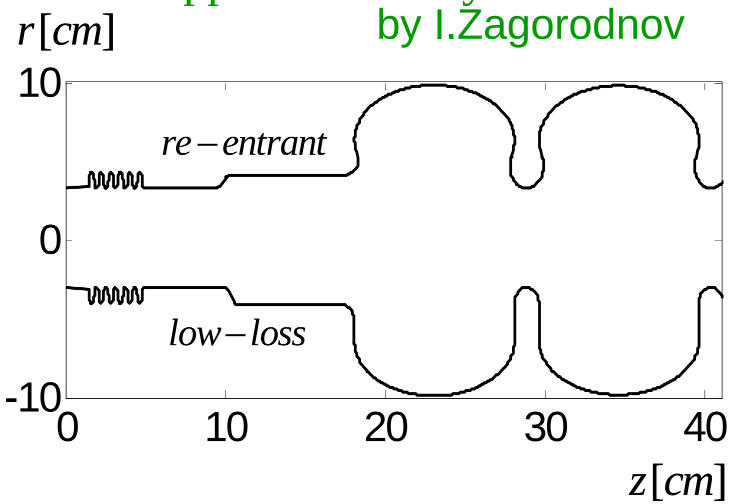
Wake field calculations

In the periodic structure the short range wake functions can be approximated by the relations:

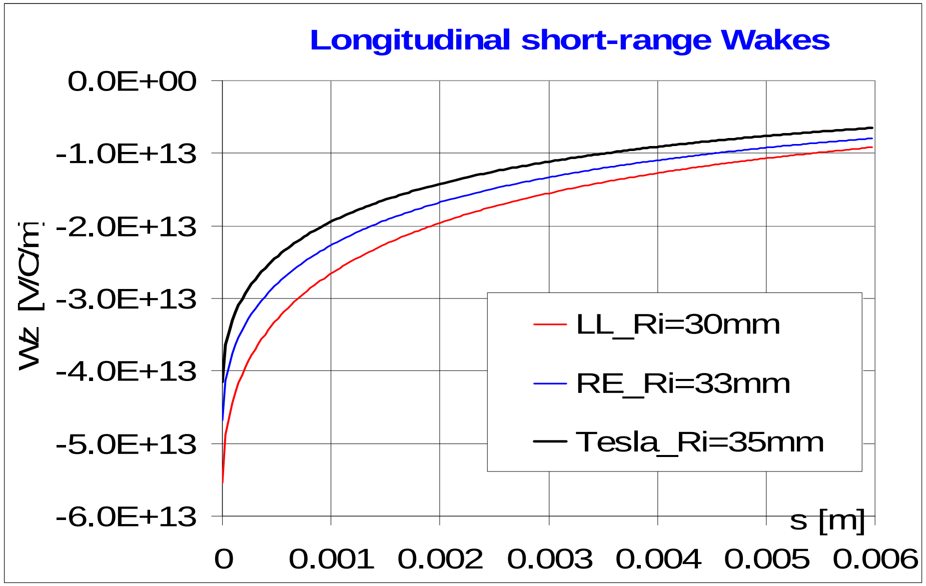
by I.Zagorodnov

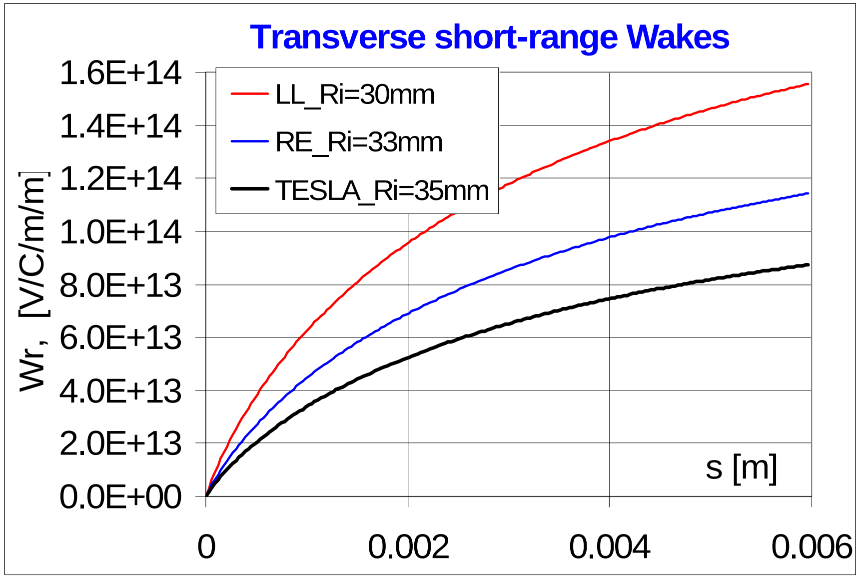
$$w_{\parallel}(s) = L\frac{Z_0 c}{\pi a^2}\exp(-\sqrt{s/s_0})$$

$$w_{\perp}(s) = \frac{2}{a^2} w_{\parallel}(0) 2 s_1 \left(1-\left(1+\sqrt{s/s_1}\right)\exp(-\sqrt{s/s_1})\right)$$



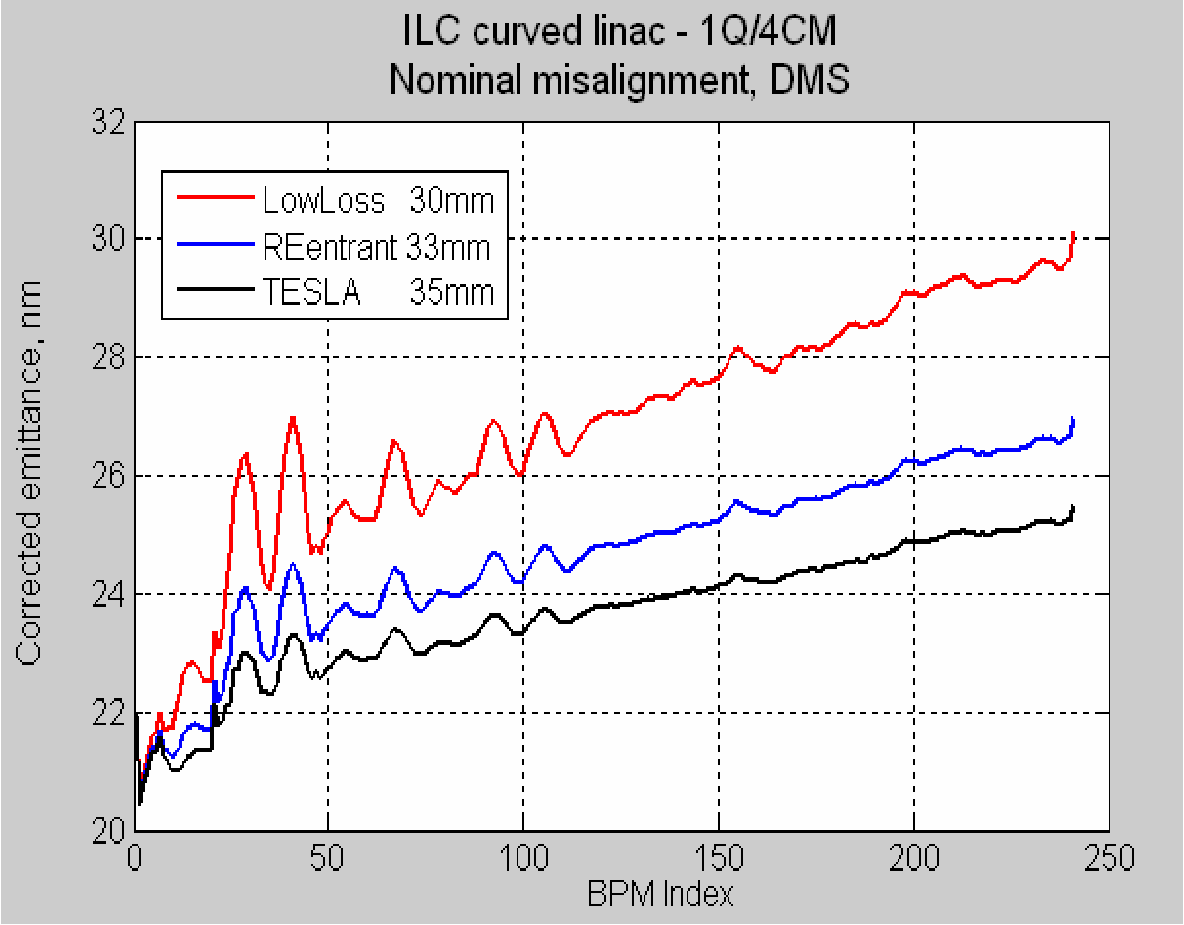
Where L, s_0, s_1 - are fit parameters to be defined.





Wake field calculations

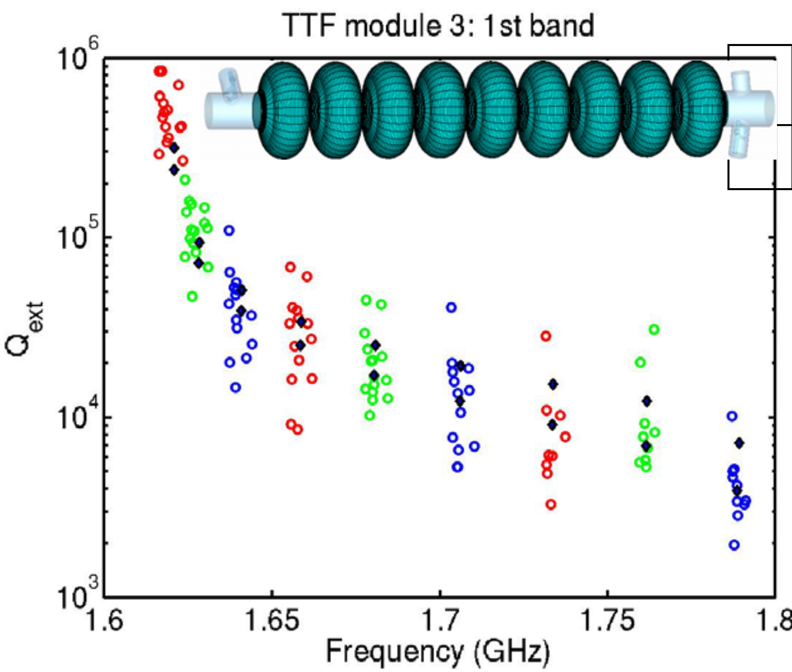
Corrected Emittance Dilution vs. BPM index for different wakefields



No bump correction was applied. Dispersion bumps - effective way to reduce emittance

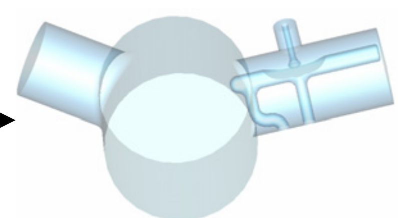
Studies of the High Order Mode for ILC cavities

- Preliminary results of Multi-bunch emittance preservation indicate that the effect of random frequency errors down the complete linacis extremely beneficial! However, attention must also be paid to modes trapped in cavity. These can lead to a large emittance dilution! (R. Jones)
- What we are doing:
  - R/Q and Q_{ext} for a few first pass bands in real solid model
  - Q_{ext} scattering due to cavity imperfections and inter-cavity spacing
  - Optimization (new design) of HOM coupler

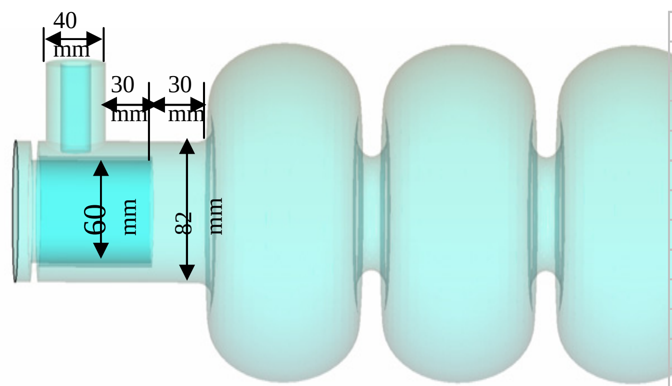


Measured Q_{ext} in 8 cavities(CM#3).

Large Q scattering in 1st HOM band



Baseline ILC cavity and HOM coupler



F, MHz	Qext	Rsh/Q	mode
1300	8.00E+05		M1
1696	1.65E+03	22968	D1
1721	2.88E+03	93247	D1
1747	5.59E+03	32916	D1
1902	1.76E+04	72992	D2
1917	2.77E+04	158985	D2
1931	4.60E+04	89321	D2
2420	1.03E+05	180097	D3
2424	1.96E+04	202969	D3
2829	1.99E+04	8000	D4
3072	1.74E+04	8266	D5
3335	1.42E+05	15618	D6

Alternative design for cavity, HOM and Main Coupler (coaxial coupling to cavity) provide good HOM damping

Deliverables in FY06/Projections for FY07

ML Lattice Design : Finalize the ILC Main Linac Lattice for curved Linac including undulator and matching sections at the start/end (RDR document)

Static tuning studies

- ✓ Complete detailed LET calculations for this lattice, including the specifications for the alignment, resolution, beam jitter and also perform failure mode analysis (RDR document)

LET Simulation tool development: **CHEF & OPTIM**

- ✓ Complete all benchmark exercises.
- ✓ Implement BBA algorithms, perform static alignment studies for curved linac and also start with the dynamic studies

Dynamic tuning studies : Start dynamic tuning (including vibration and ground motion) and perform beam-based feedback studies

Start-to-end simulation : Start integrated LET simulation on Bunch compressor + ML + Beam delivery system

Dark current estimate: Estimate the fraction of captured dark current

Electromagnetic: full cryomodule wakefield computations

Start beam-beam @ IP studies, add quantum effects in beam-beam code

Expectations for FY07 and beyond: This work is expected to continue in FY07 and beyond. We expect that these activities will increase to 5-10 FTE as more accelerator physicists and engineers get involved with the design, engineering and cost reduction.

Summary

- Working on the various aspects of the ILC simulation:
  - ✓ ML lattice design, static tuning studies, benchmarking exercises, (collaborating with International groups on these studies)
  - ✓ Development of LET simulation tools

  For RDR document
  - ✓ Complete ML lattice design
  - ✓ Complete static tuning studies
  - ✓ Create specs for alignment tolerances, magnets & cavity stability
  - ✓ Wakefield calculations

  Projections
  - ✓ Diagnostic section requirements
  - ✓ Soon start with the dynamic tuning studies
  - ✓ Also work on the Integrated simulations of static and dynamic effects across all sub-systems from DR exit to IP
  - ✓ Beam-beam studies at IP

Backup- Misalignment tolerances

ab initio (Nominal) installation conditions

Tolerance	Vertical (y) plane
BPM Offset w.r.t. Cryostat	300 μm
Quad offset w.r.t. Cryostat	300 μm
Quad Rotation w.r.t. Cryostat	300 μrad
Cavity Offset w.r.t. Cryostat	300 μm
Cryostat Offset w.r.t. Survey Line	200 μm
Cavity Pitch w.r.t. Cryostat	300 μrad
Cryostat Pitch w.r.t. Survey Line	20 μrad
BPM Resolution	1.0 μm

- **BPM transverse position is fixed, and the BPM offset is w.r.t. Cryostat**
- **Only Single bunch used**
- **No Ground Motion and Feedback**
- **Steering is performed using Dipole Correctors**